Passive Solar Potential In Commercial Buildings Four Case Studies

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PREFACE

The development of low-e coatings and plastic inner glazings has resulted in windows with thermal resistances significantly greater than standard double-glazing. With these "super-windows", perimeter (and, therefore, total) building heat loss is drastically reduced. By incorporating atria and daylight controls into buildings, lighting requirements can also be significantly reduced. In commercial buildings with large glazing areas (e.g., office buildings), the use of "super-windows" and daylighting strategies can have significant impact on building dynamics and energy costs. The size and capital cost of the heating and cooling plant and distribution systems can be dramatically reduced for passive solar commercial buildings.

This report presents four case studies describing how passive solar design principles can be used to reduce commercial building energy consumption and capital cost. This project was originally intended to perform a detailed examination of three buildings that successfully combined all aspects of passive solar design. A review of commercial buildings across Canada found that, although many buildings have one passive solar feature (e.g., atrium, high-performance windows, daylighting controls), very few could be considered as having a truly integrated passive solar design.

As a result, two changes were made to the original terms of reference. First, the three case studies were expanded to four, with less in-depth analysis of each. Second, two of the case studies discuss how a single passive feature has been applied in numerous buildings instead of focussing on a single building.

The feature that was the most difficult to find in commercial buildings was high-performance windows. It seems that this building sector has been slow to grasp the benefits of this technology. One posible means of overcoming this defficiency would be to sponsor a design (and build) competition.

The case studies have been written to be easily understood by architects, engineers and their clients. It is recommended that the case studies be included in the EMR technical note series for distribution to building designers.

RéSUMÉ

La mise au point d'enduits à faible émissivité et de vitrages à recouvrement interne de plastique a donné naissance à des fenêtres dont la résistance thermique est beaucoup plus grande que celle des fenêtres à double vitrage ordinaires. Grâce à ces fenêtres performantes, les pertes de chaleur des édifices reliés au pourtour (et pour ainsi dire du bâtiment tout entier) sont singulièrement réduites. Dans les édifices commerciaux munis de grandes surfaces de vitre (dans les immeubles à bureaux, p. ex.), le recours aux fenêtres performantes et à l'éclairage naturel peuvent avoir des effets significatifs sur la dynamique d'un bâtiment en termes de coût énergétique. La dimension des systèmes de chauffage, de refroidissement et de ventilation ainsi que des coûts qui y sont rattachés peuvent être sensiblement réduits, dans le cas d'édifices commerciaux munis de système solaire passif.

Le rapport présente quatre études de cas qui démontrent comment les systèmes solaires passifs peuvent servir à réduire la consommation énergétique d'un bâtiment aussi bien que les coûts d'investissement requis. A prime abord, on avait voulu réaliser un examen détaillé de trois édifices pour lesquels on semblait avoir réuni avec succès tous les aspects de conception de systèmes solaires passifs. Un survol des édifices commerciaux au Canada a révélé que de nombreux édifices présentent des caractéristiques normalement attribuées aux systèmes solaires passifs (ex.: solarium, fenêtres performantes, éclairage naturel) mais peu possèdent de véritables systèmes solaires passif intégrés.

Par conséquent, on a jugé bon de modifier les termes de références de départ. Premièrement, on a revu les études de cas prévues; de trois études on en a fait quatre qui comportait chacune moins d'analyses en profondeur. Deuxièmement, deux études de cas montrent comment appliquer un aspect habituellement associé au solaire passif à de nombreux édifices plutôt qu'à un seul édifice.

La caractéristique la plus difficile à trouver dans les édifices commerciaux est sans contredit les fenêtres à haut rendement énergétique. Dans ce secteur du bâtiment, il semble que les designers aient été lents à comprendre les avantages qu'ils pouvaient tirer des fenêtres performantes. Une bonne façon de remédier à cette lacune serait de commanditer un concours de conception et de construction.

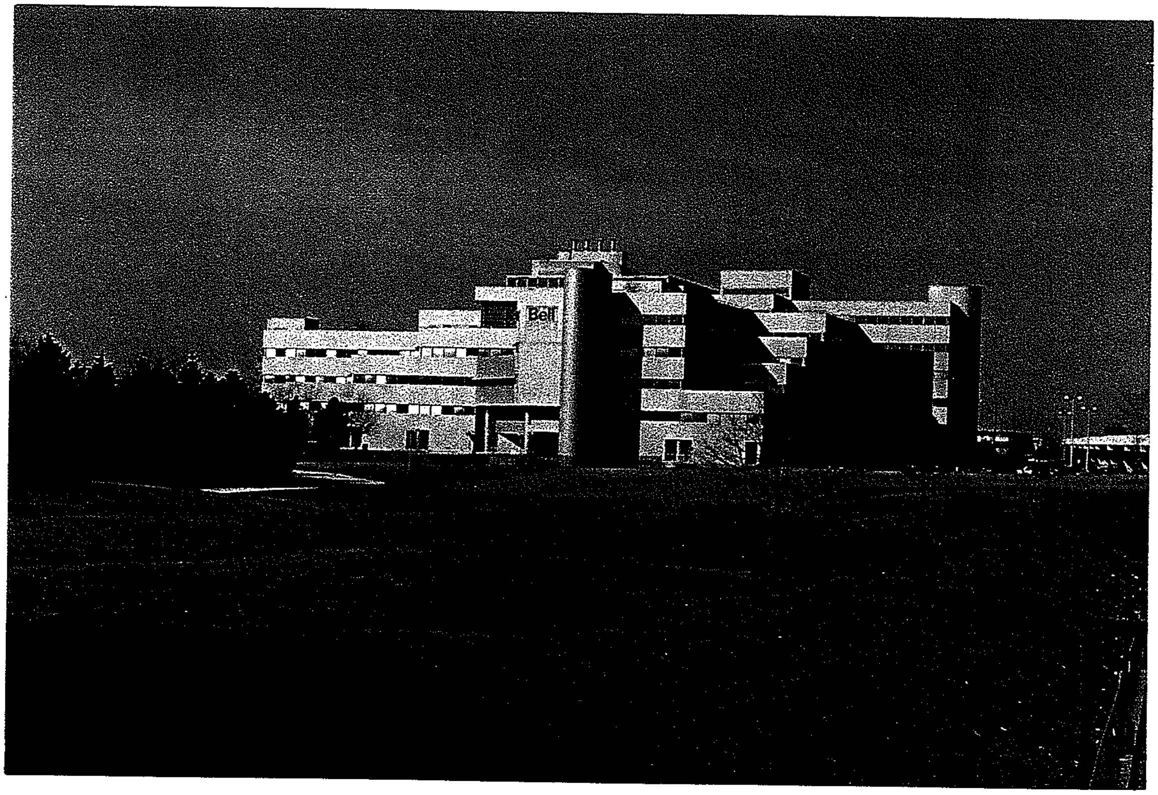
Les études de cas ont été rédigées à l'intention d'architectes, d'ingénieurs et de leurs clients. On recommande que les études de cas fassent partie de la série de fiches techniques d'EMR aux fins de distribution aux intervenants dans le domaine du bâtiment.

PASSIVE SOLAR DESIGN IN AN OFFICE BUILDING:
A CASE STUDY

INTRODUCTION

Office buildings are characterised as having high internal gains and large window areas; how can passive solar design principles be used to reduce energy consumption in this type of building? The Bell Canada Administrative Centre in Scarborough, Ontario, demonstrates that passive solar design principles can be used to reduce energy consumption by over 60%. The building designers achieved this dramatic reduction through the addition of a central-plan atrium and improvements in the building envelope, mechanical and lighting systems.

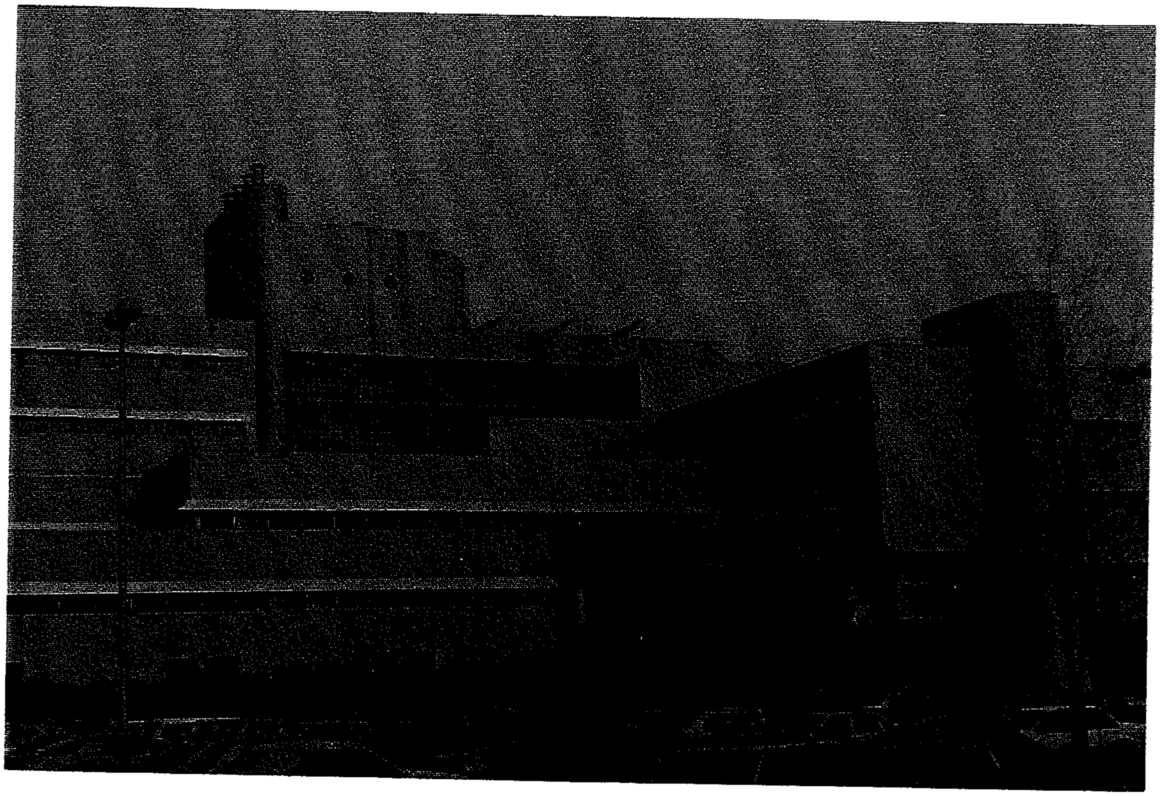
The design concept for the Bell Canada Administration Centre (100 Borough Drive, Scarborough) was to minimize cooling, heating and lighting loads. This was accomplished by carefully selecting window size and type and making maximum use of the available daylight and solar energy. The building has six floors of open-plan office space surrounding a central atrium, which contains a cafeteria and eating area. Most of the 35,000 square-metre building is devoted to office functions. Although the building has a single tenant, the different requirements of the various departments made the design of the building like a multi-tenant building.



Bell Canada Administration Centre, Scarborough, Ontario.

Building Envelope

Most office buildings are heavily glazed on all facades. The intent is to provide a continuous view to the outdoors, but some method is needed to limit the solar gains on sunny days. Reflective or tinted glazings are the usual choice. These glazings, however, also reject the winter solar gains and do nothing to reduce the peak heating load. The designers of the Bell Canada building chose a better solution: the window area is sized to minimize heating and cooling loads, yet provide sufficient daylight. This is done without comprimising the view by placing the windows in a continuous strip at eye level. The window-to-wall ratio is 36%, significantly less than the 65% ratio found in many office buildings. The windows are untinted triple-glazed units (with a thermal resistance 50% higher than standard double-glazing). The R20 walls are also more energy-efficient than walls of standard construction. The overall thermal resistance of this assembly is over four times greater than the conventional all-glass system.

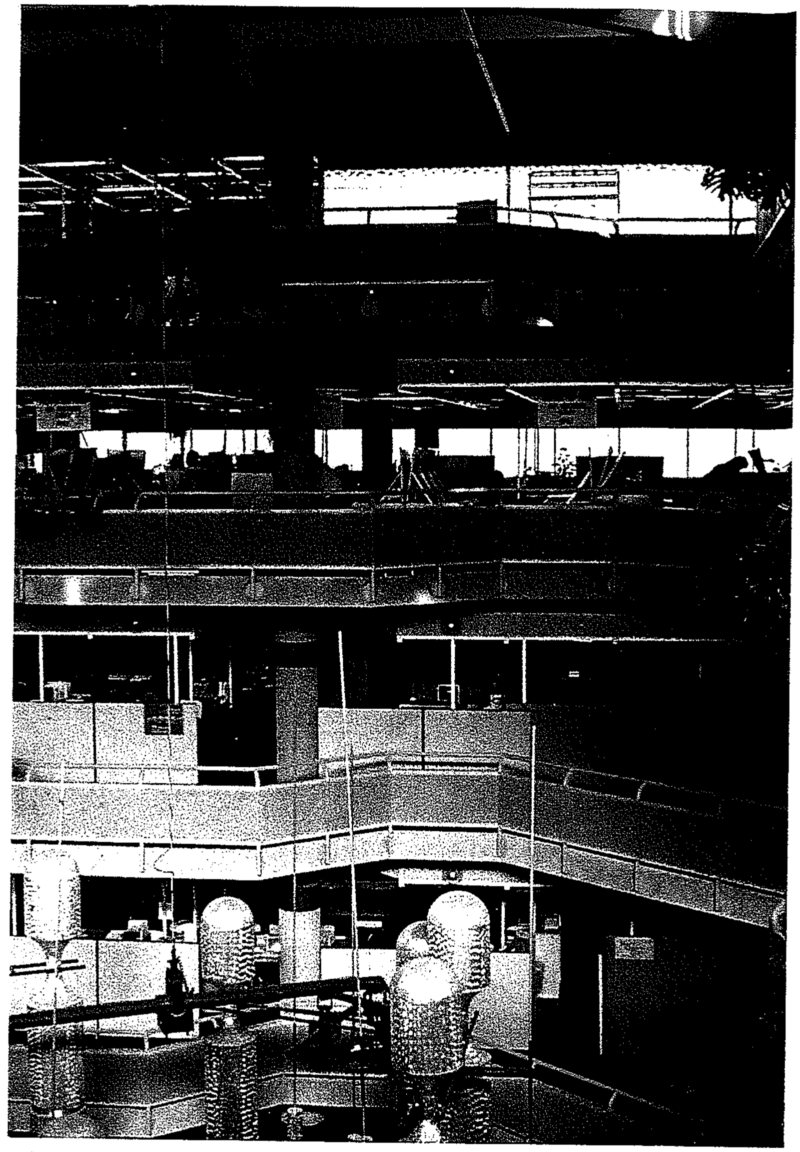


The south-face of the Bell Canada Office shows the modest use of windows and glass block wall for the upper floors.

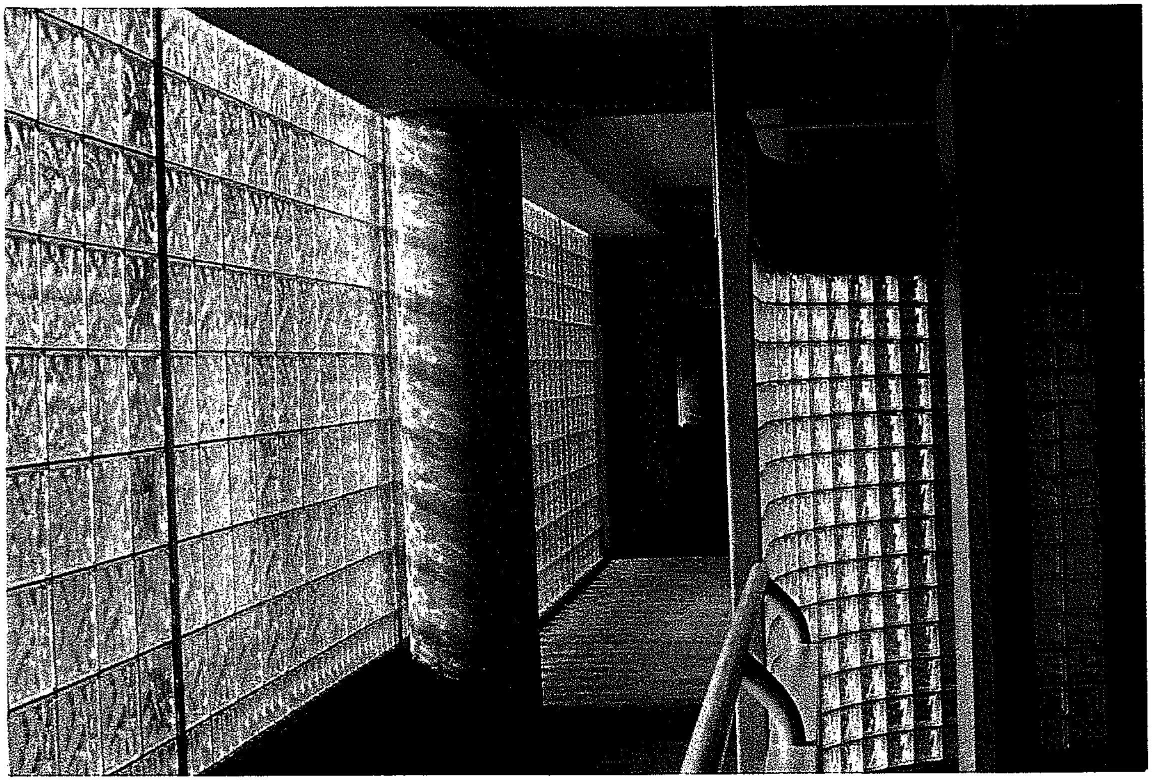
The south-side of the building was designed differently from the other facades. Slotted metal awnings are used on the south windows instead of reflective coatings to reduce glare and summer cooling loads. Glass block is used extensively on the south-side of the top two floors. This glass provides diffuse natural light to enter the upper offices and the atrium without the glare associated with standard windows. The thermal resistance of glass block is only slightly poorer than standard double-glazing. Glass block has a typical daylight transmission of 62% (although it can vary between 50 and 85 %) as opposed to standard double-glazing at 81%.

Slotted metal awnings block the summer sun.

The atrium allows daylight to reach the inner offices.



Clerestories over the atrium reflect natural light into the building.



Glass block provides diffuse natural light for
the building interior.

Atrium Design

The dominant feature of the building interior is the central atrium. This feature creates an antidote to the claustrophobic atmosphere of most multistorey offices, and allows natural light to penetrate into the centre of the building. Daylight enters the atrium through south-facing glass block walls and clerestories in the roof above the atrium. Because the clerestories are oriented vertically and face north and east, they provide diffuse light to the atrium floor.

The clerestories are also used for smoke control: in the event of fire, several of the glazed panels open, and the natural chimney effect in the atrium accelerates the venting of smoke through the ceiling.

Mechanical and Lighting Design

The various passive solar design features at the Bell Canada office have resulted in smaller heating and cooling loads than a conventional office building, so that smaller (and, therefore, less expensive) HVAC equipment is used. Moreover, the mechanical system has been designed using several low-energy principles to further reduce operating costs.

Because much of the building has high internal heat gains (e.g. switchboards, computer, cafeteria), the mechanical system is primarily devoted to meeting the cooling load for the building. The most novel feature of the mechanical system is that the chillers operate at night, when outdoor temperatures and electricity demand are low. The cooled water is stored in large water tanks in the basement of the building, to be used to offset the cooling load for the following day. This uses the equipment to its best advantage (chiller efficiency increases as outdoor temperature decreases). This operation could also be used to reduce costs in regions where off-peak power rates are available.

Fan coil units provide perimeter heating. Because of the high insulating value of the windows and walls, perimeter heating is only required on very cold days. The small heating requirement means that the fan coil units can be small and mounted in the ceiling, thereby increasing the usable floor area.

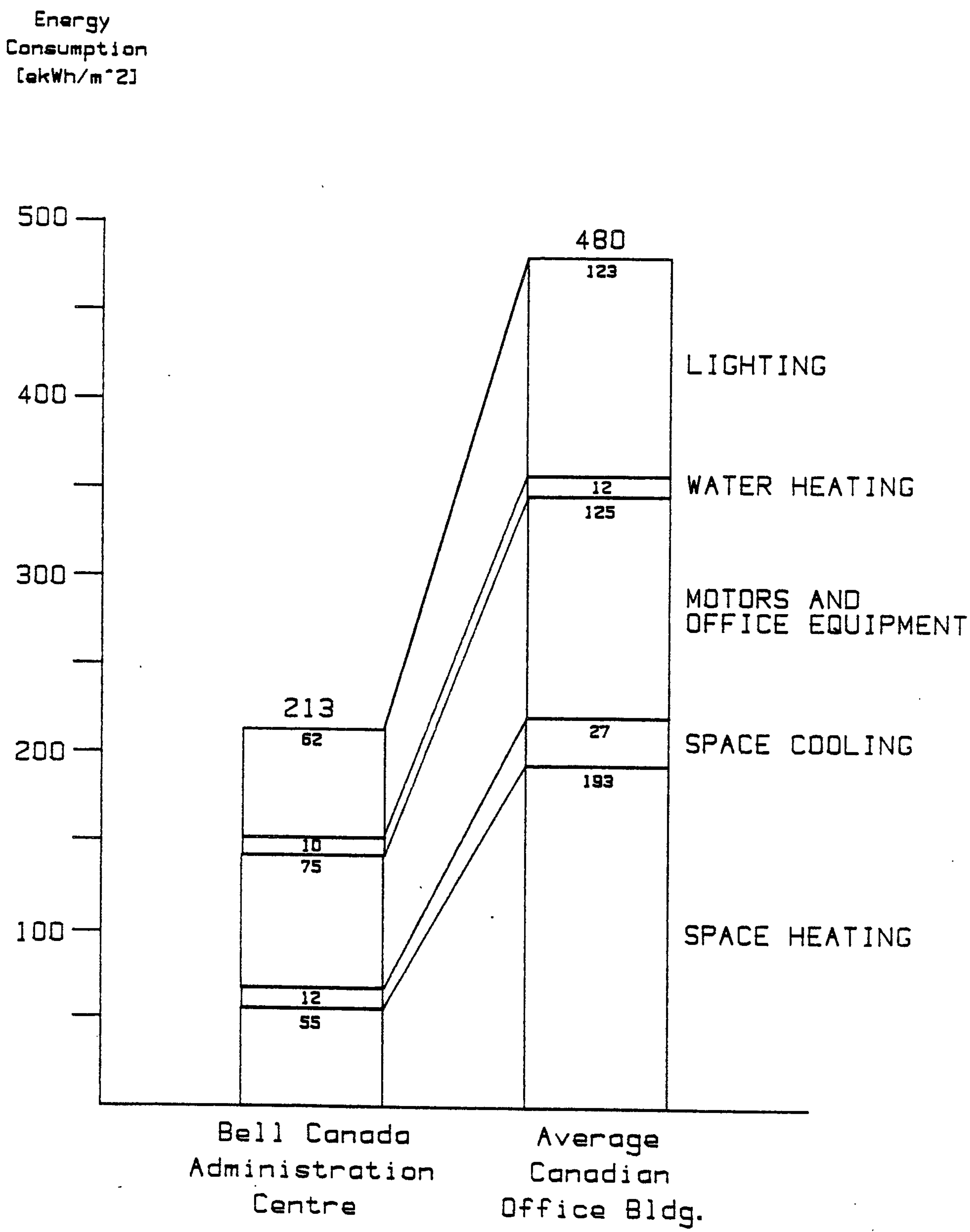
The atrium is lit by low-pressure sodium lights. Although their colour rendition is unsuitable for office work, these high efficiency lights are an appropriate choice for the atrium. The artificial lighting in the atrium and adjacent walkways is controlled by a simple on/off photocell, and is automatically shut off when natural lighting provides sufficient illumination for general requirements.

The operation of the mechanical and lighting systems are controlled by a building automation system, which shuts down fans and lights when the building is unoccupied.

The Final Result

The average office building in Canada uses 480 equivalent kilowatt-hours per square metre of floor area. The Bell Canada building has an annual energy consumption of only 213 eWhr/m2: less than 45% for that of an average office building. This is achieved despite the long operating hours and high energy use of telephone-switching and restaurant equipment.

An analysis was made of the energy use within the building. The biggest energy savings when compared to a standard office is for space heating. The energy-efficient building shell reduced space heating costs by 70% over a conventional office. The energy requirement for lighting is half that of a standard office, largely due to the effect use of daylight.



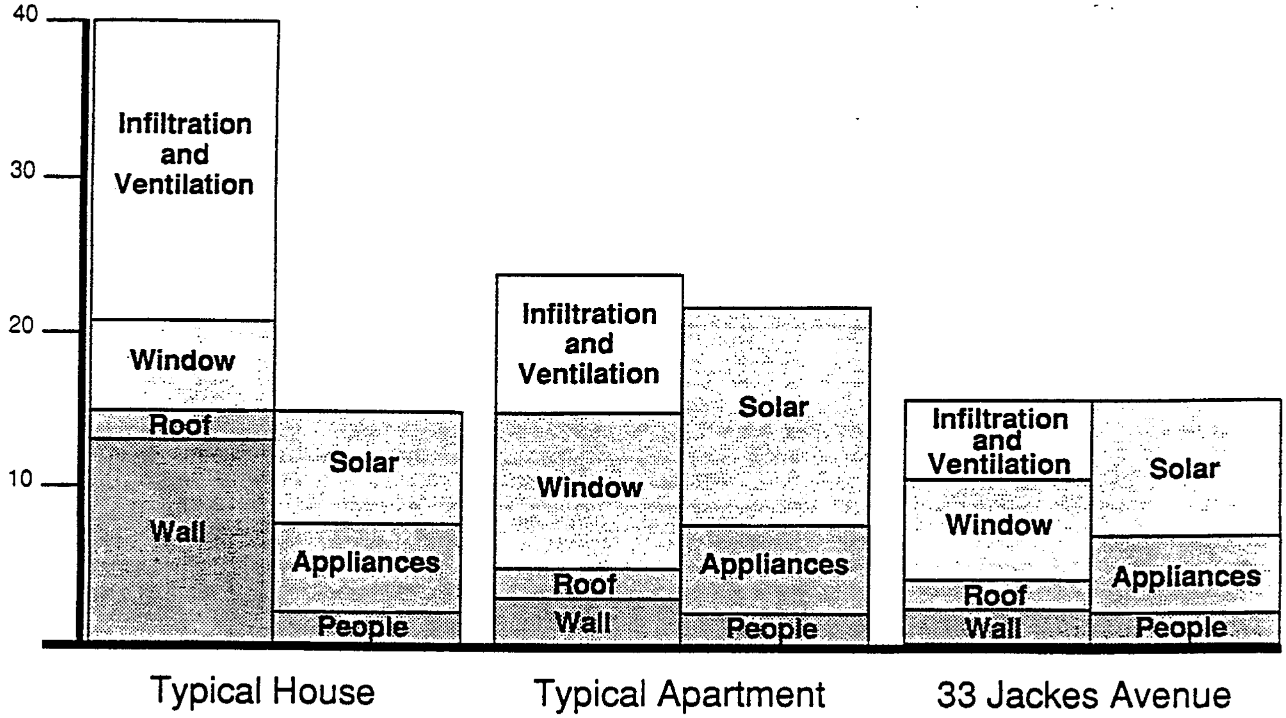
Energy Consumption in Office Buildings

PASSIVE SOLAR DESIGN IN AN APARTMENT BUILDING:
A CASE STUDY

Introduction

The developers of 33 Jackes Avenue wanted a luxury building--individual suite control of heating and cooling, maximum thermal comfort, and many common amenities--yet one that would be competitively priced in the Toronto market. The creative application of passive solar/energy-efficient design principles achieved these objectives and cut the annual energy consumption in half--and with little or no increase in capital cost. This case study documents how the building envelope, mechanical systems and other services were designed to reduce annual energy consumption by over 160 kilowatt-hours per square metre of floor area.

33 Jackes Avenue Condominium Apartment Building (Toronto).



Thermal Loads at 0°C Ambient Temperature

Building Envelope

In the design of a typical apartment, the building envelope is designed separately from the mechanical systems. Typically, the architect or owner usually selects large expanses of double-glazed windows for each apartment and the engineer is forced to use some form of baseboard heating system to overcome the large window heat loss. The design at 33 Jackes Avenue called for triple-glazed windows and higher than normal wall insulation levels (R20 walls and roof). The superior thermal performance of this wall/window selection eliminated the costly requirement of baseboard heating underneath the windows. Heating and cooling requirements can therefore be handled by a centrally-located system serving each apartment. The premium cost of triple glazing is partially offset by the elimination of perimeter baseboard heating. Thermal comfort is improved because the interior glass temperature is almost five degrees Celsius warmer than it would be if double-glazing were used.

Window sizing in each apartment is related to energy efficiency. The trend with luxury apartments is for floor-to-ceiling glass, resulting in over 70% of the exterior wall being glazed. This large glass area causes high cooling loads and high energy consumption. By using narrower floor-to-ceiling windows and positioning the windows where views are the best, the Jackes building gives the feeling of large glass areas with only a 48% window-to-wall ratio. Because each suite has windows facing in two cardinal directions, it is possible to position the glazed areas to minimize summer solar gains. Areas of east- and west-facing windows are kept as small as possible, and much of the glazed area is shaded by overhanging balconies.

Tall Corner and Bay Windows give the feeling of large glass areas.

Mechanical Systems

A water-source heat pump loop is used as the heating and cooling system at 33 Jackes. This system redistributes thermal gains and losses throughout the building in an attempt to achieve an overall heat balance. Water is circulated throughout the building at a temperature that varies between 15 and 30 C. Individual heat pumps in each suite use this water as a source or sink for heat. Each heat pump can automatically switch from heating to cooling depending on the apartment space temperature. On a sunny cold winter day, heat pumps on the south side of the building will be working to cool apartments while heat pumps on the north side of the building will be in the heating mode. The water loop connecting the heat pumps allows all heat pumps to trade their thermal gains and losses to optimize heating and cooling.

If the water loop temperature exceeds 30 C, heat is rejected to a cooling tower. A back-up heater comes on if the water loop temperature drops below 15 C. Back-up heating is required for the coldest winter days when the building heat losses are greater than the building heat gains. Gas-fired boilers are used for all backup heating for the heat pump systems. Domestic hot water is heated by electric elements in storage tanks located in each suite. Domestic hot water use is thereby included in tenant metering.

The use of individual heat pumps for each condominium apartment has two other advantages: 1. Allows each owner to precisely control his space temperature according to his/her needs at any time of the year. 2. Allows each tenant to be separately metered for his/her heating and cooling through the electricity meter.

Other Services

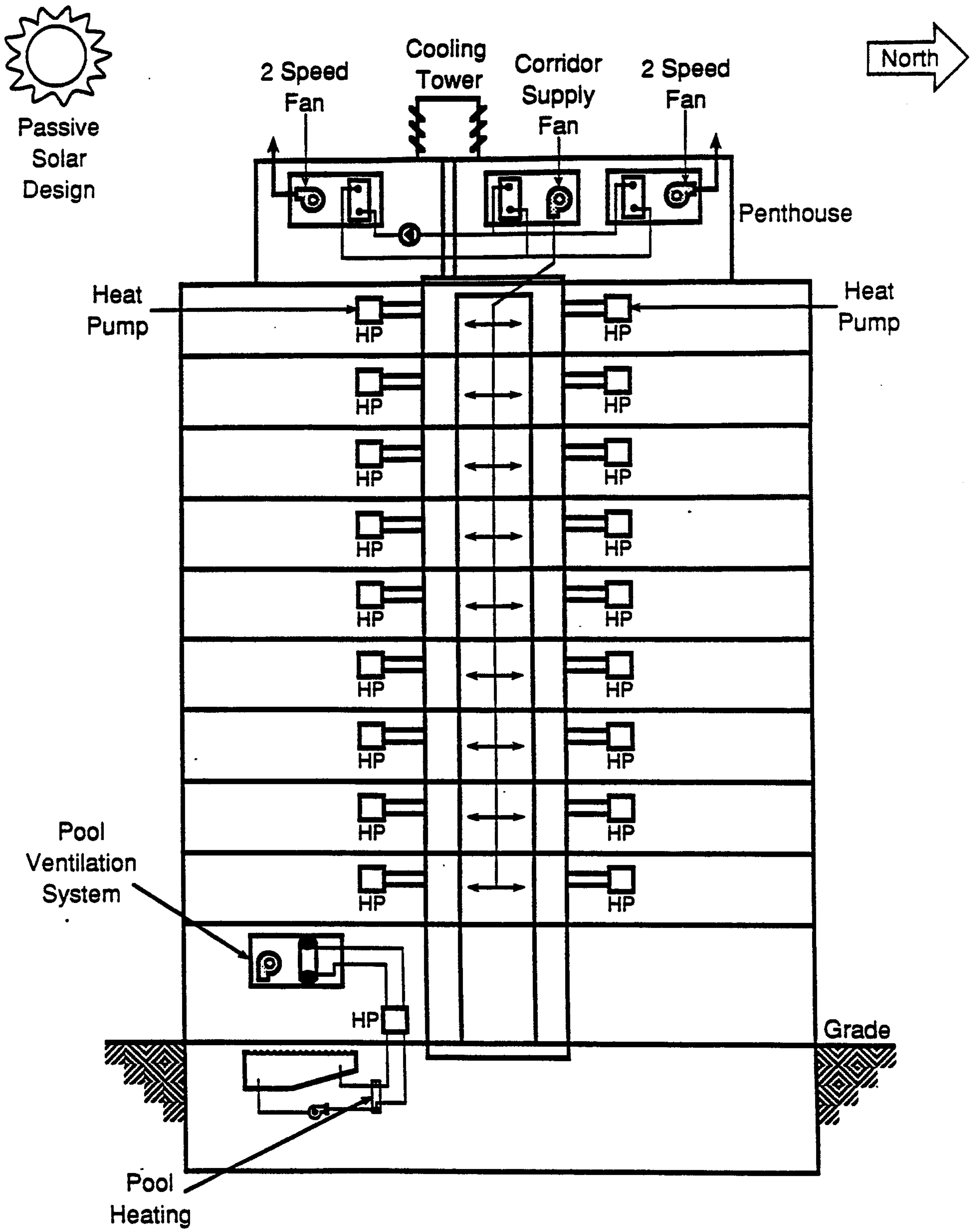
The heating load due to ventilation was minimized by using heat recovery and two-speed ventilation fans. Heat recovery from exhaust air is provided by a glycol run-around loop with heat exchange coils in the corridor make-up unit and exhaust fan units. Two-speed ventilation is accomplished at 33 Jackes Avenue by providing a two speed motor for fan drive ventilation systems. Low speed is selected for normal conditions. High speed is used for free cooling in spring or fall conditions. The exhaust fans use two speed motors and are interlocked with the ventilation fan operation.

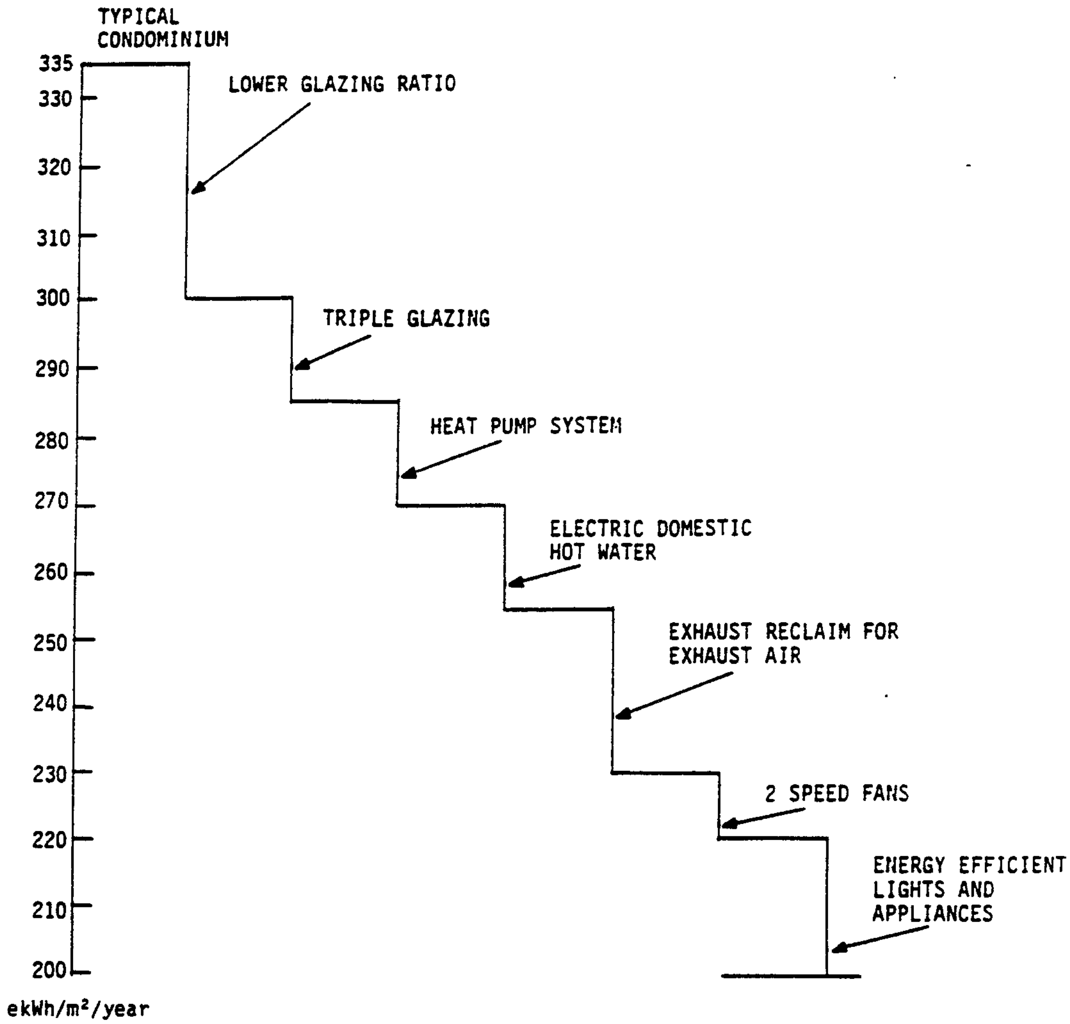
The heat gains from lights and appliances are reduced by using the most energy-efficient models. Compact and tube fluorescent lights were used extensively in the corridors, suites and common areas. The standard appliance package included high-quality low-energy use models (e.g. self--cleaning oven).

A packaged heat pump system is used for pool water and air heating. The heat pump dehumidifies the pool air and transfers condenser heat to the pool water.

The car ramp and garage are designed to conserve energy. By locating the garage under the building, the surrounding earth is able to keep the garage above freezing and eliminate the need for heating. The car ramps are partially protected by a terrace deck thereby reducing the amount of electric snow melting cables in the ramp.

PROPOSED INDIVIDUAL HEAT PUMP SYSTEM SCHEMATIC for 33 JACKES AVENUE



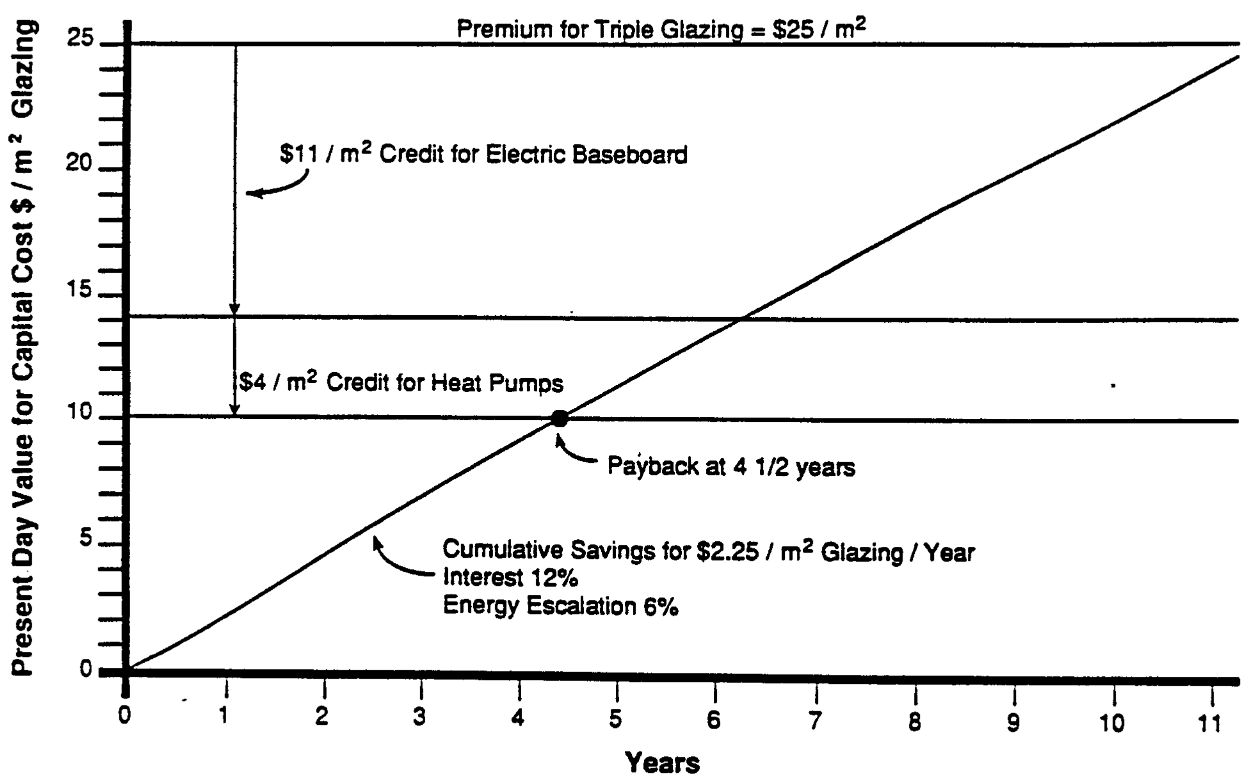


Staircase to Energy Efficiency at 33 Jackes

The Investment Opportunity

All of the energy saving measures used at 33 Jackes were implemented at little or no additional cost. This is true even for the two capital-intensive items: the heat pump loop and triple-glazing. Almost all of the incremental cost of the suite heat pumps over standard fan coil units was offset by the savings due to the elimination of the chiller. Because the water loop is always close to room temperature, further savings were achieved by not insulating the water loop piping.

The selection of triple-glazing provides energy savings of $2.25 per m2 of glass area per year at 33 Jackes. The premium cost of triple glazing was $25.00 per m2 of glass area. At first look, the sample payback period of 11 years does not look attractive to a developer. Selection of triple-glazing provided some additional first-cost savings. Normally, electric baseboard heaters are added beneath large double glazed windows. The high-performance glazing does not require the baseboard heating for comfort. The first-cost saving is $11.00 per m2 of glass area. Heat pump size per suite can also be reduced, due to smaller heating and cooling design loads. The first-cost savings is $4.00 per m2 of glass area. With these credits, high-performance glazing in condominiums has a good return on investment. The true payback period for triple-glazing is 5 years, after allowance for credits on baseboard heating and heat pump sizing, and adjusting for 12% interest costs and 6% energy escalation.



Economics of Triple Glazing

Design Concept

The application of low-energy design and passive solar heating principles to high-rise residential apartment buildings differs from application for single-family dwellings. Houses can be characterized by large thermal losses and modest heat gains. Low-energy design dictates reducing losses and increasing gains to reduce this imbalance. Apartments, on the other hand, have less exterior area per occupant and tend to use more glass. The result, in an apartment building, is that losses are lower and gains are higher, to the extent that they are nearly equal on a typical winter day. The design of HVAC equipment for most apartments does not take advantage of this balance, such that simultaneous heating and cooling is required for most of the year.

The approach taken with 33 Jackes was to reduce losses and gains and use a mechanical system that allows excess gains to be transferred to areas of high heat loss. This concept impacts on the design of the building envelope, mechanical systems, and other services. Although the 29 luxury suites average 275 square metres in floor area, the design principles used at 33 Jackes can be applied just as effectively in more modest-sized apartments.

The Final Result

The predicted and monitored energy performance for 33 Jackes is

	Natural Gas	Elec.	Total
	--- in ekWhr per m2 of floor area ---		
Predicted	45.0	155.0	200.0
Monitored (1988)	66.6	139.2	205.8

Electricity use is 10 % below the design budget, whereas natural gas usage is 48% over budget for the first year of operation. The higher--than-expected fuel usage is attributed to the increased ventilation caused by the continuous high-speed operation of the exhaust and ventilation fans. Control modifications were completed in March 1989 and should result in reduction of fuel use to the design value.

Had 33 Jackes been built to standard practice, calculations show that it would have consumed 335 ekWhr/m2, fairly close to the energy consumption of the average Canadian apartment building (380 ekWhr/m2). Therefore, the actual energy consumption of 33 Jackes is almost half that of a typical apartment building. The energy consumption of 33 Jackes is even more impressive when compared to the high energy use of other luxury apartments (which feature amenities such as swimming pools and large glass areas).

USING DAYLIGHTING IN COMMERCIAL BUILDINGS

Introduction

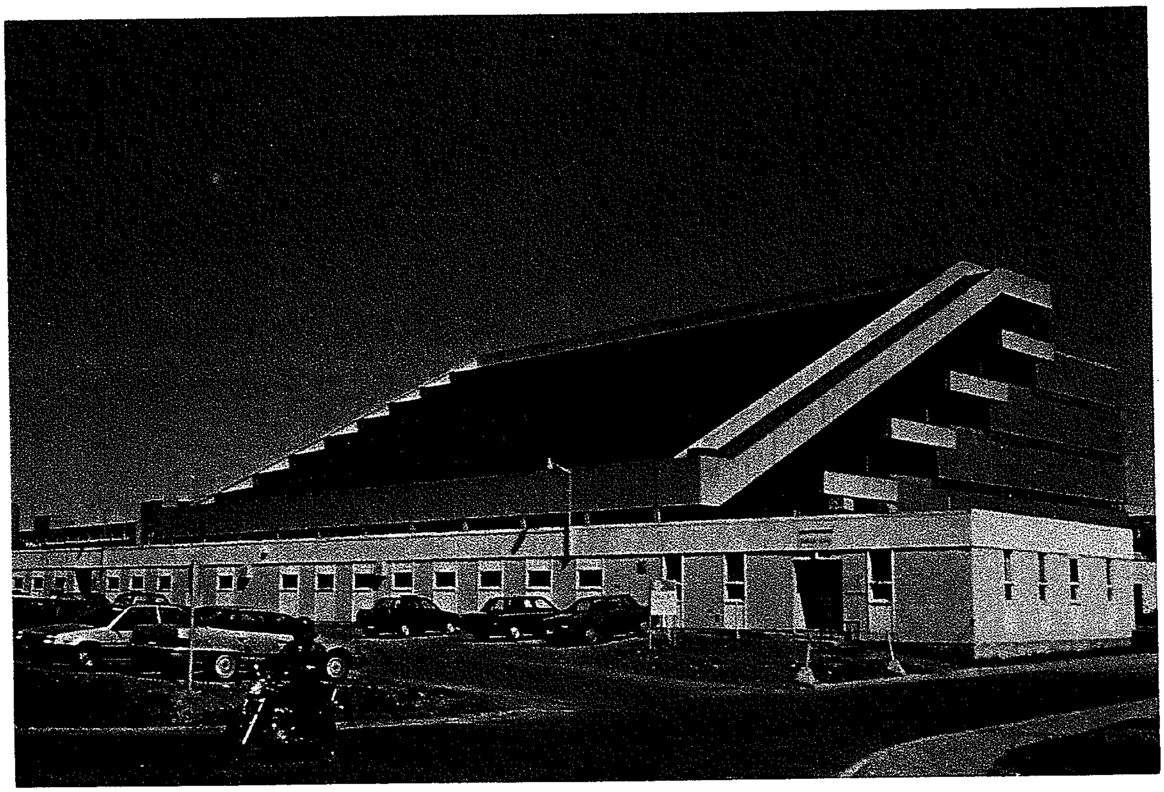
In most offices, electricity used for artificial lights is the largest building operating cost. The effective use of daylighting can reduce this cost by over 40% and reduce the peak cooling load (and therefore equipment size) by 25%.

Daylighting features must be incorporated into the building at the design stage, requiring collaboration between the architect and the mechanical and lighting engineers. The architect's role is to design a building envelope and interior and to select windows that allow daylighting to penetrate into the building without causing glare. The engineers must design the lighting and HVAC systems to respond to fluctuations in daylighting and solar gains.

Building Envelope

The first consideration in daylighting design is to select a building form that allows daylight to serve as much of the building as possible without causing glare or excessive solar gains. Two approaches have been used with success: long east-west axis buildings, and atria.

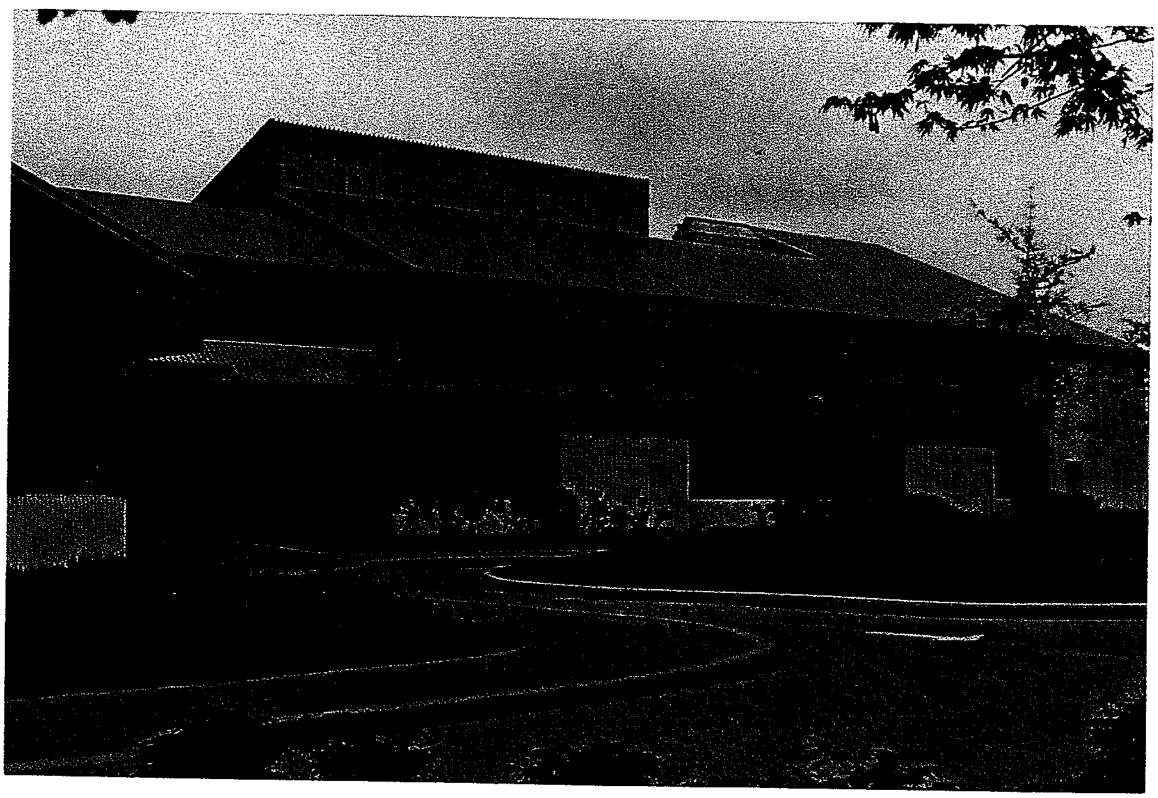
Buildings aligned on a north-south axis receive most of their daylight on the east- and west-facing building facades, but the low morning and evening sun on these orientations cause glare and high solar gains, which are difficult to control through shading. North-facing windows, on the other hand, receive mostly diffuse light, and south-facing windows can be protected from direct sunlight with overhangs. The Memorial University Library in St. John's, Newfoundland is an interesting example of an east-west axis building. The building is terraced on the north side to maximize entry of diffuse sunlight for reading, and uses few east and west windows to avoid glare.



The Memorial Library in St. John's has north-facing windows to maximize diffuse daylight.

Glare and summer solar gains can be further reduced through the use of overhangs and awnings on south-facing windows. Recessing windows and tilting the windows towards the ground are also effective in reducing solar gains.

Vertical glazings used in clerestories and atria are a good means of getting daylight into the building interior. For most of the year, the daylight entering these windows will be reflected downward, producing a diffuse light source. Sloped glazings and skylights, on the other hand, are less effective because of high summer heat gains and potential for snow build-up in the winter. In general, atria are used for functions that do not require fine control of light levels--in fact, the sunlight patterns in central-plan atria may be used to help create an outdoor feeling. The Townsend (Ont.) Municipal Building provides a good example of the use of clerestories to provide natural light to the building interior.



The Townsend Municipal Building uses clerestories and a water-loop heat pump system to make maximum use of the light and energy from the sun.

Interior Design

The key requirement in designing the building interior for daylighting is to match space function with daylighting availability. Daylighting works best where modest fluctuations in light levels are acceptable (for example cafeterias, meeting areas, corridors, and entrances). Where possible, these areas should be located around the perimeter of the building or in the atrium. In many modern offices, an ambient lighting system is used to establish a general lighting level; task lighting provides additional light at the work station. With these systems, offices can be located at the building perimeter with natural light used to provide the ambient lighting.

The depth into the building that daylighting can be used depends on the window location and wall surface treatment. Natural light can contribute to interior lighting requirements up to a depth of 2 to 2.5 times the height of the windows (measured from the floor to the top of the windows). Thus, a window located high on a wall will be more effective than a low-mounted window. For a typical office, optimum use of daylighting will occur in rooms five to six metres in depth. Conveniently, this distance corresponds to standard design practice. Reflective surfaces (such as light shelves) can be used to increase daylight penetration into the building interior, but can be costly and, if used on the inside, can reduce the effectiveness of the interior space.

Daylight penetration can be enhanced inexpensively by proper selection of the interior finish. The ceilings should be white, and walls light green or light yellow, with a flat (i.e., non-glossy) finish to diffuse the incident light.

Window Selection

The window type can have a significant impact on the effectiveness of daylighting. Windows need not be oversized for effective daylighting; it is more important to select windows with the right thermal and optical properties.

For daylighting applications, windows should have a high visible light transmittance and a low solar heat gain transmittance, implying that ultraviolet and infrared radiation are blocked without any appreciable loss of visible light. (Visible transmittance is the percentage of the visible spectrum that passes through the window. Solar heat gain transmittance is the percentage of the total solar radiation, including infrared and ultraviolet, that results in a heat gain to the building.) Table 1 lists the properties of various types of glazings. Windows with low-emissivity plastic inner glazings or green tints have the best daylighting properties; grey-tint windows are the poorest for daylighting applications.

OPTICAL PROPERTIES OF DIFFERENT GLAZINGS

Double-Glazed (6mm glass)	Visible Transmittance (%)	Solar Heat Gain Transmittance (%)
Clear	80	71
Bronze/Clear	47	50
Green/Clear	67	48
Gray/Ckear	37	48
Clear Low-e	86	60
Low-e Plastic Inner Glazing	69	57

The selection of window treatment can help reduce window glare. Diffuse (i.e. frosted) glass or glass block may be an inexpensive solution, depending on the desirability of providing a view for the building occupants. Alternatively, translucent drapes or blinds can be automatically or manually closed to reduce glare and opened when a clear view of the environment is desired.

Lighting Design

Daylighting is by nature dynamic (the intensity of available sunlight varies with time of day, cloud cover, variation in air pollution, etc.), and lighting control strategies must account for this variation. The economic benefit from daylighting comes from turning off or dimming electric lights when sufficient natural light is available. The better the lighting control system can respond to fluctuations in natural light, the greater the energy savings will be.

The first step in lighting design is to lay out the lighting circuits to take advantage of daylighting. The perimeter lighting on each side of the building should be on the same circuit, but separate from the other sides. In this way, these separate circuits can be controlled as a group. Even if daylighting controls are not being installed initially, proper zoning of the lights will make retrofits easier.

Manual control of lights does not generally make effective use of daylighting, as lights tend to be turned on in the morning and not turned off until night. Moreover, occupants may turn on more lights in a daylit room to attempt to equalize indoor and outdoor brightness levels. A more acceptable design incorporates photocell controllers to reduce artificial lighting in response to increases in available daylight, with a manual override to allow the occupants to increase interior lighting as needed for specific tasks.

There are three automatic lighting control systems: on-off, multistage, and variable. With the on-off system, a photo-sensor causes lights to be turned off or on at a set lighting condition. This type of system works best in areas where variations in interior lighting intensity can be more readily tolerated, such as foyers, cafeterias, corridors, and atria.

Multistage controllers operate by shutting off or turning on single bulbs in a multi-lamp fixture, in response to ambient lighting levels. These are generally satisfactory in providing ambient or background lighting where task lighting is used at the desk. Some companies supply pre-wired fixtures that can be simply plugged together to provide one-, two-, or three-bulb lighting. This type of fixture has been used successfully in the Hong Kong Bank of Canada Building in Vancouver. Excessive or rapid variation in light intensity can be quite distracting to the building occupants, however. To avoid occupant discomfort, multistage systems work best when controlled by a building automation system. The system can control the on-off level of each stage and the frequency of cycling.

Continuous variation of fluorescent lighting is effected by using either special dimmable ballasts or proportional energy controls to vary the power input to the fixture. Proportional controllers, although less expensive than the dimmable ballast, can only vary the output of the fixture over a limited range (typically 75 to 100% of maximum output). The Southland Office Building in Calgary uses a dimmable system. The perimeter lighting fluctuates in response to daylight levels and drops to a minimum level at night for janitorial work.

The Southland Office Building has an automatic dimmable lighting system to reduce lighting and cooling costs.

There are several approaches to daylighting design: the most consistent (and the easiest to understand) are outlined in the Illuminating Engineering Society Lighting Handbook. The essence of any daylighting design procedure is to consider the windows as a light source of known brightness and luminous efficacy.

HVAC System Design

One of the major advantages of natural lighting systems is that the peak cooling load is reduced, so that a smaller air-conditioning system can be used. Peak cooling loads occur on bright summer days, when electrical lights are most probably off or dimmed to their lowest level. Much of the cost of the lighting control system can be offset by the savings in capital cost of chillers, piping and ductwork (in addition to the savings in lighting energy).

The Final Result

The lighting control system used in the Southland office building in Calgary was analyzed to determine the effectiveness of daylighting controls. The computer analysis for this 30000 square metre building showed that the lighting control system is capable of reducing both the lighting and cooling energy consumption by 40%: an annual savings of over $25000. The peak cooling requirement was reduced by over 25%. The savings in chiller equipment cost was estimated to be another $75000. Building Operations staff note that the dimmable lighting fixtures have similar maintenance requirements to the more conventional fixtures. The system provides flexibility in the adjusting the light levels to the various tenants. The building tenants are happy with the system and, in fact, most are unaware of its operation.

ATRIUM DESIGN FOR SAVING ENERGY IN COMMERCIAL BUILDINGS

Introduction

The atrium is fast becoming one of the most popular features in upscale commercial buildings. The open feeling, large glass area and landscaped interior of the atrium transform the ordinary office block into an attractive and productive workplace. Atria provide a further benefit: they can, if designed correctly, reduce the energy costs associated with heating, cooling, and lighting of the interior space at a construction cost below conventional office buildings. To design energy-efficient atria, four factors must be considered:

- function and form
- glazing area, slope and orientation
- mechanical design
- lighting design

Function and Form

An atrium affords the architect greater flexibility in the design of commercial buildings. The first step in atrium design is to determine the role of the atrium in the building. Atria can used as a building entrance, a link between buildings or areas within a building, a focal point or a place to congregate. In many cases, the atrium can be used for a function different from the rest of the building. Many offices buildings locate cafeterias or shopping areas in atria. Hotels use atria as the lobby area or for housing recreation facilities.

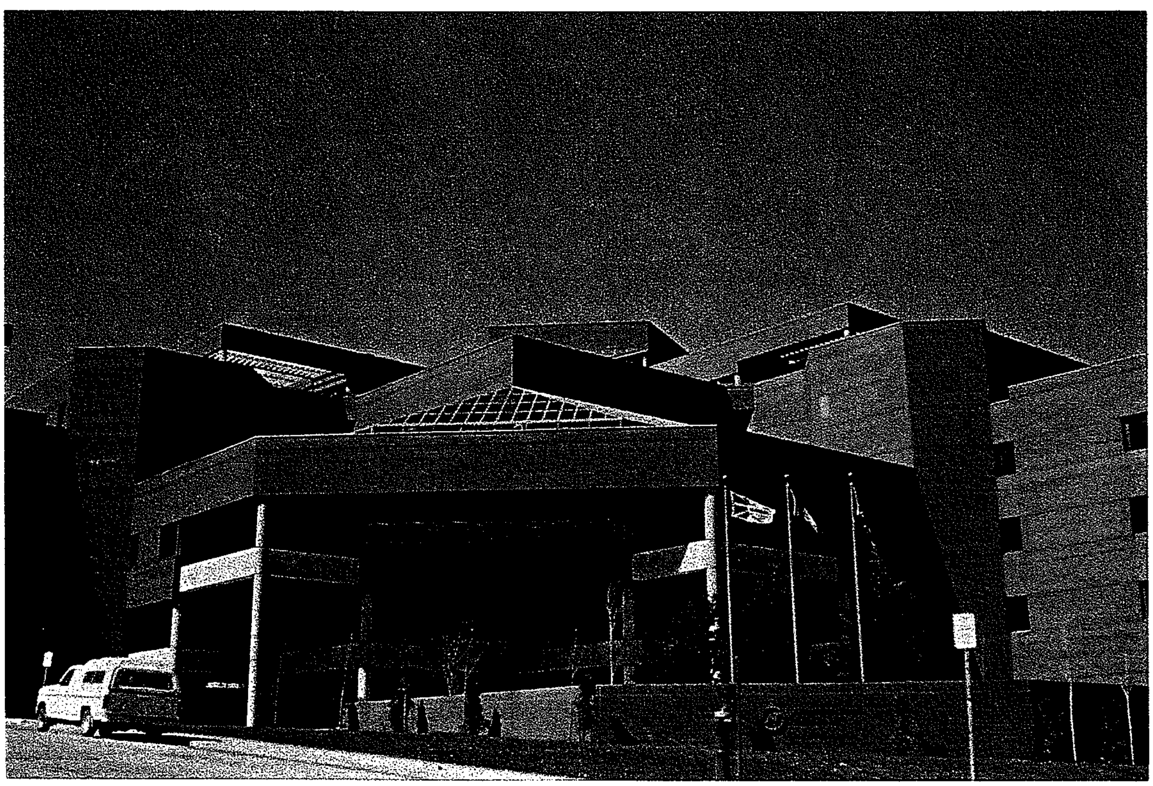
The atrium configuration is not suitable for all buildings; noise concerns limit the application of atria in apartments and hotels (except in lobbies). The same caveat is applied to mixed-function buildings: functions which are inherently incompatible, such as libraries and restaurants, should not be combined in the open-air atmosphere of an atrium. Atria should be avoided in office areas where the variations in lighting and temperature may be unacceptable to workers.

Some people view atrium as a waste of space, yet it can make very efficient use of building space. Because atria can be used as walkways and atrium buildings are generally low-rise, less work space is wasted on elevators, washrooms and corridors. Thus, more rentable floor area is available and higher rents can often be charged for the offices that face the atrium. The atrium itself may provide attractive rental space for a restaurant or public exhibits (e.g., art galleries or small trade shows). Also, some zoning laws permit increases in allowable rental space associated with covered public pedestrian space.

The atrium can be used to create interesting building form. The atrium, when used on the outside of the building, can provide a striking geometric profile; on the inside, it can be used to generate visual contrasts in an otherwise uniform rectangular building.

An atrium should be no higher than five storeys for effective use of daylighting and for fire safety considerations. This does not prohibit the use of an atrium in a high-rise building, however: the atrium can still be used on the uppermost floors, or as an entrance.

The Southport Office Building in Calgary uses atrium exhaust air to heat the underground parking garage.



The Newfoundland Telephone Building uses its atrium for heating the ventilation air for other parts of the building.

Mechanical Design

The large glass areas in atria provide lots of heat and light; good atrium design makes use of these gains to reduce lighting, heating, cooling and fan energy costs. One design approach uses an unconditioned or partly conditioned atrium as a breezeway between the outside and the conditioned space. This buffer space is not cooled or lit during the day. The front entrance of the Lionel Chevrier Office Building in Cornwall, Ont. operates in this manner.

An atrium can be used as a return plenum, to facilitate air handling and waste heat recovery. In this approach, air from the work space is returned to the atrium, where heat can be recovered from exhaust air and return air can be conditioned. Ventilation air can be introduced into the atrium and mixed with supply air. A major advantage of this system is the savings in ductwork and fan energy. The Southport office building in Calgary uses such a system: heat from the building air handling system is discharged to the atrium, which acts as an exhaust plenum. Exhaust air is used to provide free heating to the underground parking garage. Heat recovery ventilators can also be installed at the top of the atrium to extract useful heat from the exhaust air before it is vented to the atmosphere.

The Bank of Hong Kong Building in Vancouver has atria as an entrance way and as a penthouse feature.

In choosing the atrium form, the designer must decide on the link or coupling between the atrium and the rest of the building. Decoupled atria are separated from the rest of the building by windows and walls, and are used to limit transfer of noise and heat. Coupled atria are not separated from the rest of the building, thus providing a link between work space and amenity space.

Glazing Area, Slope and Orientation

The amount and orientation of atrium glazing has a large impact on building energy use. Atria should not be over-glazed; glass areas should be as small as possible without compromising the background natural light and openness that is characteristic of atria. Atria North in Toronto is an example of good atrium design. The interior courtyard atrium is three storeys high and has only a 25% glass-to-atrium floor area (but is an attractive and effective meeting place).

To improve thermal comfort, the atria windows should have a high R-value (i.e. should use low-e coatings, argon-gas fill or triple glazing). The glass should have high daylight transmission and a low shading coefficient to maximize daylighting without excessive solar gains. Green-tinted glass or low-e coated plastic inner glazings are good candidates; grey glass and reflective coatings should be avoided.

Glazed surfaces should be as close to vertical as possible to maximize winter sunlight and minimize summer solar gains. Horizontal and low-slope surfaces should also be avoided to minimize snow loading and potential water leakage problems. To further reduce summer overheating, shading devices (overhangs,louvers, or movable fabric screens) can be used. As a rule, north- and south-facing glazings are preferred over east and west orientations, as they tend to reduce overheating. Because of these factors, central courtyard and east-west linear atria (such as Bell Trinity) are more energy-efficient than atria with large expanses of east- or west-facing glass.

The atrium design at Atria North provides natural light to interior offices.

The Newfoundland Telephone Building in St. John's has an innovative system for using atrium solar gains. The building cafeteria is located in an atrium with sloped south-facing windows. The atrium provides background lighting and most of the heat required during winter daylight hours. In spring and fall, excess solar gains are removed by an air-conditioning system and transferred to the incoming ventilation air for office areas. Thus, the atrium provides heating and lighting, and cooling energy is used to reduce heating loads in the other parts of the building.

Cooling and peak electrical loads can be reduced by subcooling the atrium at night, and using thermal storage (water tanks or thermal mass walls) to provide cooling for the following day. This approach should only be used in buildings where the adjoining work area is on night thermostat setback, to avoid increasing the heating requirements in the that space.

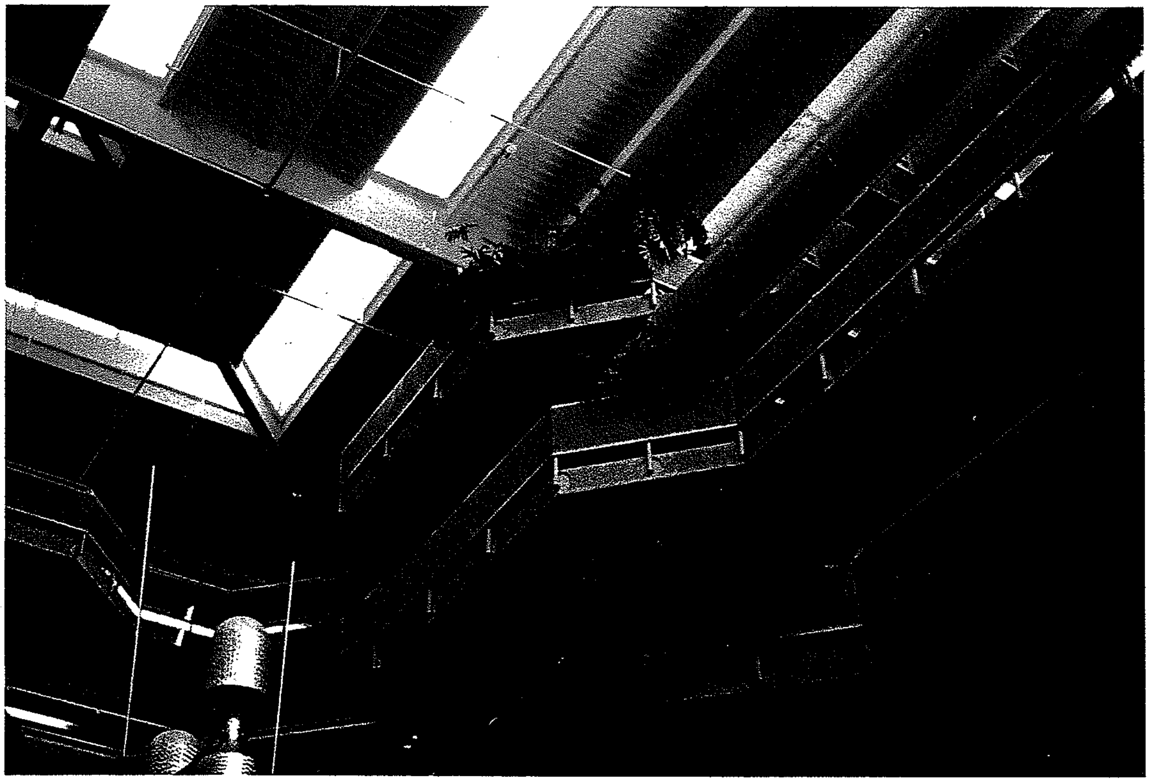
The installation cost of mechanical services can be reduced by routing ducts, pipes and elevators through the atrium. The openness of the atrium simplifies concrete form work and avoids wall and floor penetrations and pipe and duct chases.

One of the most important considerations in the proper design of an atrium is its response to a fire. A decoupled atrium is best for compartmentalization and smoke control, but a coupled atrium reduces floor-to-floor spreading (because of the way flame proliferates). In either case, the atrium can be used as an exhaust plenum for the smoke.

Lighting Design

The main advantage of an atrium in lighting design is that it allows natural light to penetrate into interior spaces. Lighting controls can be used to reduce artificial lighting when natural light is sufficient to illuminate the area. These controls can be much cruder (and therefore less expensive) in the atrium than in the work area, as the lighting requirements in the atrium are typically less stringent than those of the adjoining spaces. The atrium however, must be designed with daylighting in mind. For natural lighting to be effective in central-plan atria, the height of the atrium should be kept to under four stories. To avoid the glare and thermal discomfort associated with direct solar radiation, natural light should be reflected or screened. Clerestories, such as those used at the Scarborough Bell Canada Building are an effective means of reflecting light into the building.

As light intensity decreases with the square of the distance from the source, artificial lights should not be installed at the top of the atrium. In addition, ceiling-mounted lights are difficult to replace and less responsive to daylight sensors mounted at floor level. Artificial lights are more effective if suspended, post-mounted on lamps or in lamp clusters.



Clerestories at the Scarborough Bell Canada Office reflect natural light into the building interior.

The Final Product

Engineering Interface has compared the capital and operating costs of a well-designed atrium office building to a standard high-rise office building. In their study, both buildings had the same gross floor area, wall construction, window area (including windows looking into the atrium) and site conditions. They found that the atrium building could be built at a 20% lower cost with 4% higher rentable floor area. Although some of the savings are related to the reduction in building height, almost half the savings are due to reductions in exterior cladding and HVAC equipment costs. In addition, the annual energy consumption was 20 equivalent kWhr per square metre of floor area lower in the atrium building.

Perhaps the most important benefit of atrium buildings is the potential for increased worker productivity. The typical atrium features plants, waterfalls, and rock gardens, which provide an attractive view for the occupants (indeed, the view provided by an atrium is usually better than the exterior view, especially in winter). If this open and pleasant atmosphere results in just a one percent improvement in worker productivity, the gains will pay for the full cost of the building in under five years.